ASSESSING THE DAMAGING POTENTIAL OF NON-IDEAL EXPLOSIVES BASED UPON AMMONIUM NITRATE FERTILIZER

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1. INTRODUCTION

In the UK the last few years have seen five separate occasions when large vehicle borne bombs have been used by terrorists to inflict massive damage against commercial targets within city areas, some with loss of life of innocent bystanders. These devices have been constructed from large masses of fertiliser modified by grinding and the addition of a solid fuel to convert them into explosives. On April 19th 1995, a similar massive bomb this time allegedly based upon a mixture of prilled agricultural ammonium nitrate fertilizer and fuel oil (ANFO) was used in Oklahoma City to devastate the Federal building with severe loss of life.

Explosives based upon fertiliser are classified as non-ideal. They neither react in the same way as ideal explosives nor does their performance scale in the same manner as ideal explosives. Previous studies on non-ideal commercial explosives such as Ammonium Nitrate/Fuel Oil (ANFO) have reported that the TNT equivalence increases as the charge size increases (Reference 1)

In 1994, DERA Fort Halstead, an agency of the UK Ministry of Defence, was charged with assessing the TNT equivalence of the particular type of improvised explosive based upon modified fertiliser which was being used by the terrorists attacking UK targets. These studies were to be combined with fundamental studies into the forensic aspects of post blast effects of such large vehicle borne devices in urban environments.

The TNT equivalence of the fertiliser based explosive was required primarily by specialists in the field of assessing the interaction of the explosive and structures. Most of their computer programmes required the equivalence figure for computation. Initially studies were made of these explosives at small scale with charges of 17 kg, 37 kg and 90 kg. Subsequently nine large scale firings of these materials have been conducted at 454 kg and six at 2,268 kg. As a means of comparison, further firings of 454 kg of cast TNT and 2,268 kg of ANFO have recently been carried out. The firings have been conducted in arenas instrumented to obtain pressure and impulse with distance but have also included an assessment of the damaging effects of the charge against carefully positioned targets such as automobiles and a variety of street furniture.

These studies have shown that assessing non-ideal explosives such as these strictly in terms of single figure TNT equivalence can give a misleading and over-simplistic view of their damaging potential.

2. EXPERIMENTAL ARRANGEMENTS

Two main series of experiments have been carried out. First a series of small scale experiments using lightly confined (plastic tube) charges with a large length to diameter ratio. These charges were arranged to be 2 metres long with diameters of 110 mm, 160 mm and 250 mm. They were initiated with identical boosters (700g) of a high velocity of detonation (greater than 8,000 m/sec) plastic explosive and the velocities of detonation of the non-ideal explosives tested were measured using fibre optic probes in some experiments and ionisation probes in others. An array of pressure gauges was used to assess the free field overpressure generated by these charges along an axis perpendicular to the direction of the reaction.

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It was hoped that any variations in reaction velocity would provide a clue to the degree of non-ideality of the materials tested, the expectation being that the larger diameter charges would have a higher velocity than the smaller diameter. Plotting the change of velocity and the progression of pressure and impulse measurements would hopefully provide a predictive method for determining the pressures to be expected from much larger charges.

The results of these experiments have been published elsewhere in a classified forum. (Reference 2). However one of the most surprising results from this work was the fact that geometry made such a significant difference to the size of both the overpressure and the impulse generated around the charge. Also it was noted that the pressures and impulses generated by the non-ideal explosives produced significantly different TNT equivalencies at different ranges.

A second series of experiments were then conducted which have now extended over three years and the examination of three separate variations of non-ideal explosives based upon solid/solid mixtures of ground fertiliser and fuel, as well as commercial ANFO and cast TNT. This second series of experiments was also designed to provide information on the post blast forensic examination of urban scenes following the explosion of large masses of such non-ideal mixtures. Each cylindrical charge confined in its light steel container was surrounded by an array of street furniture typical of that which is commonly encountered in urban environments in both the US and UK.

The charges were purposely made to be contained in mild steel cylinders made of 3 mm thick steel with an approximate length to diameter ratio of 1:1. Initiation with a plastic explosive booster set into the top dead centre of the charge produced a radial symmetry from the explosive effect. Automobiles were positioned at known distances from the charge in such a manner that they would be struck cleanly by a largely unmodified shock wave and attempts were made to correlate the damage done to both the street furniture and the vehicles with the pressure and impulse measured by pressure measuring equipment positioned at intervals up to 60 metres from the charge. Again the pressure measurement array was arranged radially around the charges along each of the cardinal axes. Typical target arrays for 454 kg charges and 2,268 kg charges are shown in Figures 1 and 2.

Pressure and impulse data are only currently available fully for two types of the fertilizer/fuel mixes. The other data were generated in June of this year and are still being processed. Pressure and impulse data for two variations of ground fertilizer and solid fuel are shown in Tables 1 and 2.

Table 1
A comparison of the incident pressure/maximum pressure for two mixtures of ground fertilizer/solid fuel at 454 kg in a cylindrical mild steel container.

Range (metres)	Incident pressure (KPa)		Maximum Pressure (KPa)	
	Mixture X	Mixture Y	Mixture X	Mixture Y
15	218.5	169.4	231.5	185.5
30	60.4	35.2	60.4	35.7
45	25.2	16.9	25.2	16.9
60	18	14	18	14.3

Table 2
A comparison of the impulse data for two mixtures of ground fertilizer/solid fuel at 454 kg in a cylindrical mild steel container.

Range (metres)	Positive Impulse (Pa. sec)	
	Mixture X	Mixture Y
15	645	476
30	273	244
45	207	140
60	189	144

Typical effects on the close in vehicles positioned at 4.5 metres are shown in Figures 3 and 4. Although all the pressure and impulse data are not yet available from the comparative TNT charge, the effects on a similar close in vehicle have been recorded and that is shown in Figure 5.

3. **DISCUSSION**

The TNT equivalence of an explosive is often quoted as a single figure. This despite the fact that most tables show equivalence for overpressure and a separate equivalence for impulse (Table 3).

Table 3
TNT Equivalence for a range of explosives

Name	Equivalent Weight for Pressure	Equivalent Weight for Impulse
TNT	1.00	1.00
COMPOSITION A3	1.09	1.07
COMPOSITION B	1.11	0.98
COMPOSITION C4	1.37	1.19
HBX-1	1.17	1.16
H-6	1.38	1.15
OCTOL (75/25)	1.06	1.06
RDX	1.14	1.09
PENTOLITE	1.42	1.00
TRITONAL	1.07	0.96

The only explosive which has an equivalence of 1 for each of these is TNT, the standard. The commonest way of deriving a single figure of equivalence i.e. adding the equivalence for overpressure to the equivalence for impulse and dividing by two, can only give an unbiased result for an explosive where each of these equivalencies is equal. A glance at the Table 3 shows how rare this is.

The point made in Reference 2 was that even this idea of equivalence is only true at one particular range or at least does not take account of the fact that the equivalence of every one of the non-ideal explosives examined varies with range, and with geometry as well as varying as the charge weight varies.

Once this considerable variability of TNT equivalence of these non-ideal explosives became apparent, the solution to the authors seemed to be to provide the structural engineers and others with interests in computing the damaging effects of these explosives with graphs of pressure and impulse with range with charge weights which were representative of those being used by the terrorists. As has been mentioned earlier, the people who required the information were concerned with the effects of the blast and impulse

from these sorts of non-ideal charges on both civilian structures and military strongpoints specifically designed to withstand attack. Others with interests in the figures were concerned about the radius of effect on personnel either to establish a safe distance for security cordons to protect the general public during a threatened bombing or to know the range limit from which Explosive Ordnance Disposal personnel could safely tackle the device.

This approach again took a severe knock when the damage done to the vehicle targets at 4.5 metres was compared with the overpressure and impulses measured. The simple evidence of our eyes showed that the vehicle damage done by Composition Y was much greater than the damage done by Composition X in each of the three experiments conducted. Yet the overpressure and impulse at all ranges was greater for Composition X than it was for Composition Y. The indications from the last series of firings which included both a different fertilizer/fuel mixture and a 454 kg charge of cast TNT are that this difference is apparent with these mixtures also. The measured pressures from the TNT are more than two times that from the fertiliser based explosive but the damage to the vehicle targets is very similar.

The velocity of detonation of these non-ideal mixtures has been measured in these experiments and is around 3,500 metres/second in the direction of the detonation i.e. axially down the cylindrical charge and around 3,000 metres/second radially. This is considerably different from the measured and text book velocities of cast TNT which is just under 7,000 metres/second. When it is considered that the explosive reaction in TNT is intramolecular and that in the non-ideal fertilizer based systems is presumably intermolecular with the particles of oxygen providing fertilizer and solid fuel vast in comparison to the molecules of TNT, it is perhaps not surprising that the effects are so different.

4. CONCLUSION

Experiments have been conducted with a wide range of charge weights of non-ideal explosives based upon ground fertilizer and solid fuel to determine their TNT equivalence. The experiments have shown that there is not a single figure for TNT equivalence for these mixtures. Comparison with TNT shows that equivalencies differ significantly with range, with charge size and geometry. The non-ideal charges based upon fertilizer and solid fuel produced dramatically different levels of damage in automobiles close in to the charges which data are inconsistent with the measured overpressures and impulses.

There are a number of different theories about why this difference in the damaging capability of these non-ideal mixtures is apparently not directly related to overpressure and impulse particularly close in to the target. At the moment it would be premature to speculate too much on why this should be. However, it seemed politic to demonstrate to the explosive safety community these considerable differences and to voice the above reservations about the over simplistic use of TNT equivalence without reference to what was really being measured. There would seem to be a need for an alternative means of assessing the damaging power of these non-ideal explosive systems.

REFERENCES

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2. ISTDM 1995, RMCS Shrivenham.

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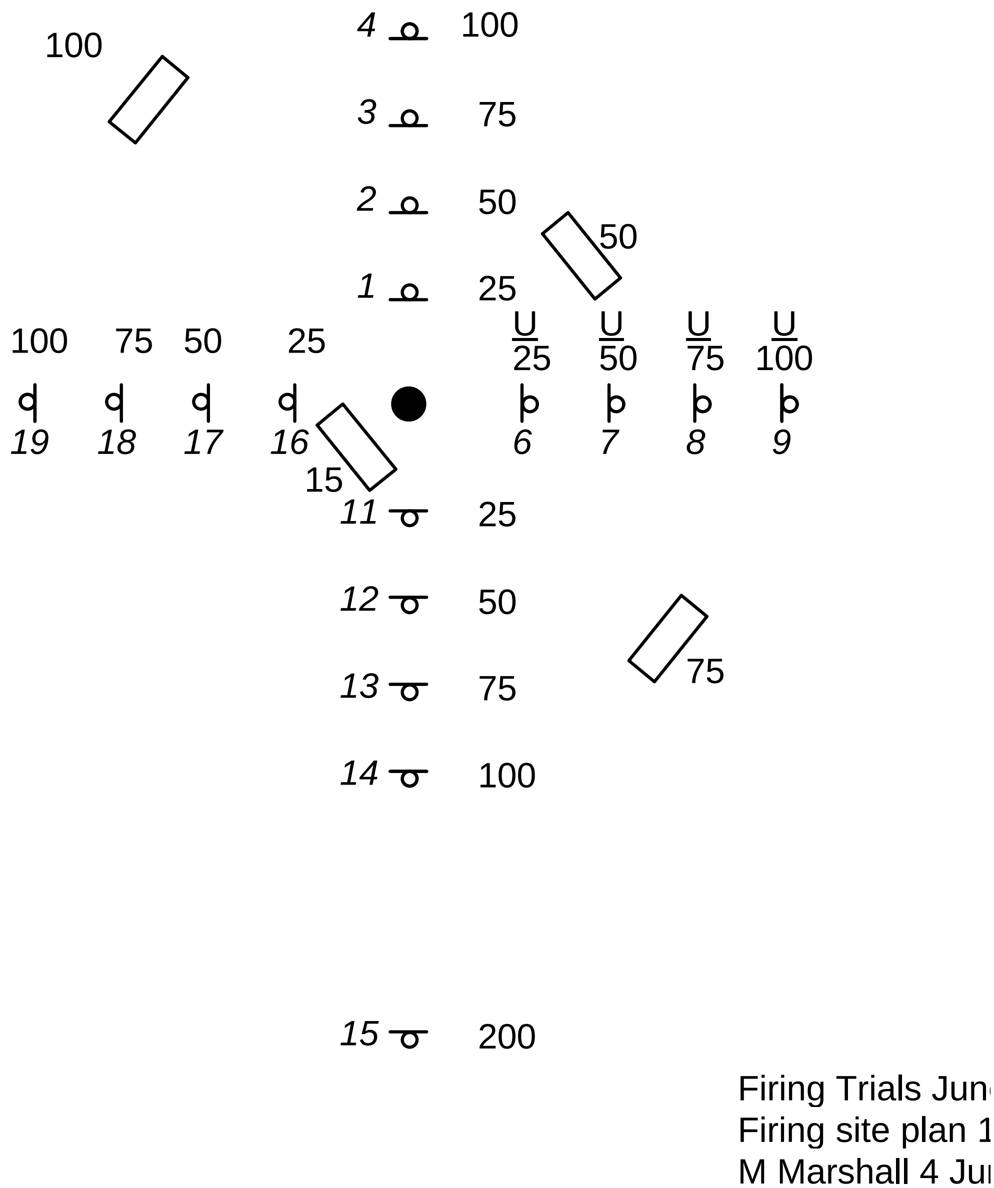

Fig.1 Target array for 454Kg charges

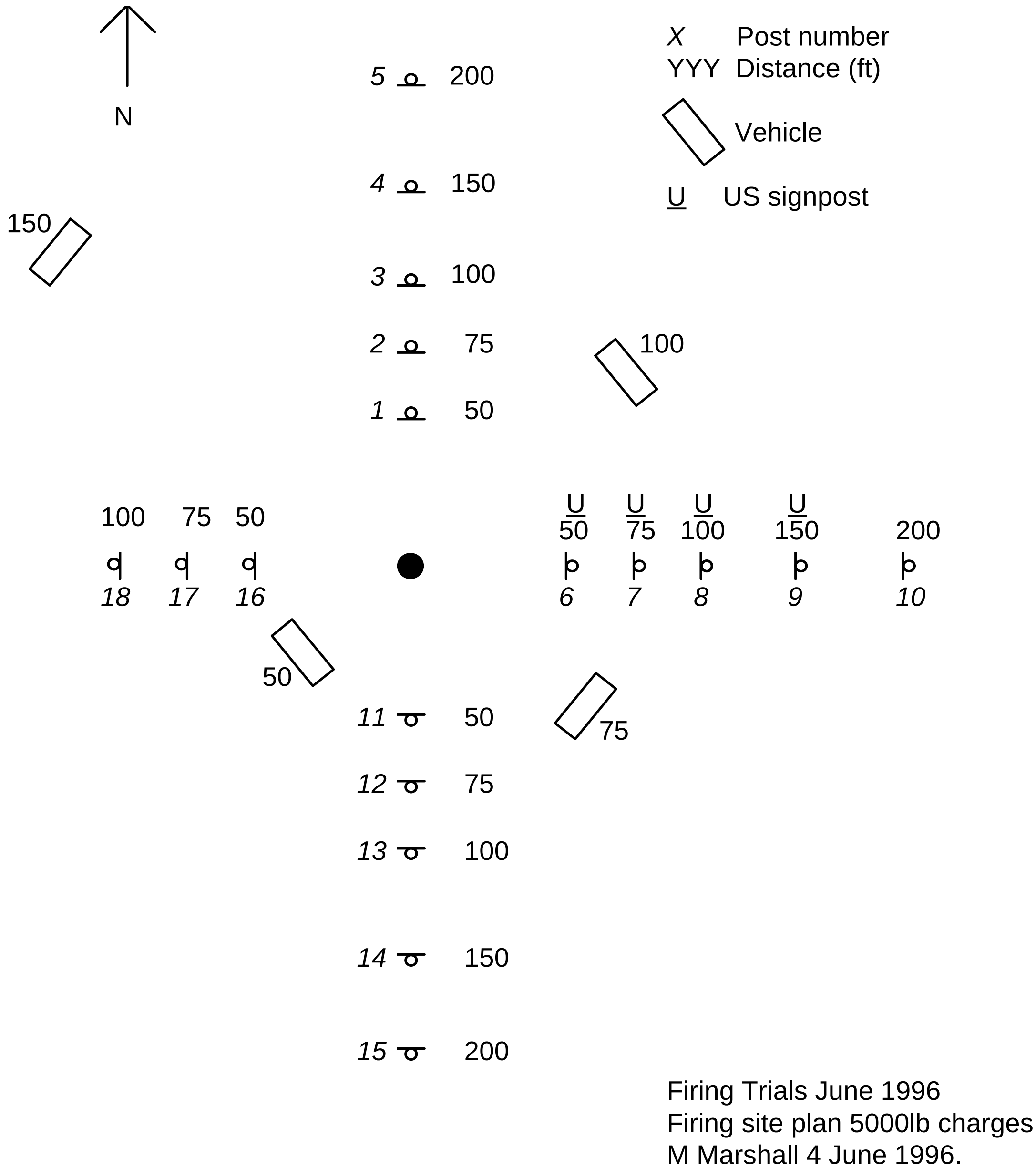

Fig.2 Target array for 2,268Kg charges

Fig.3 Target effects on a vehicle positioned 4.5m from 454Kg of Mixture X

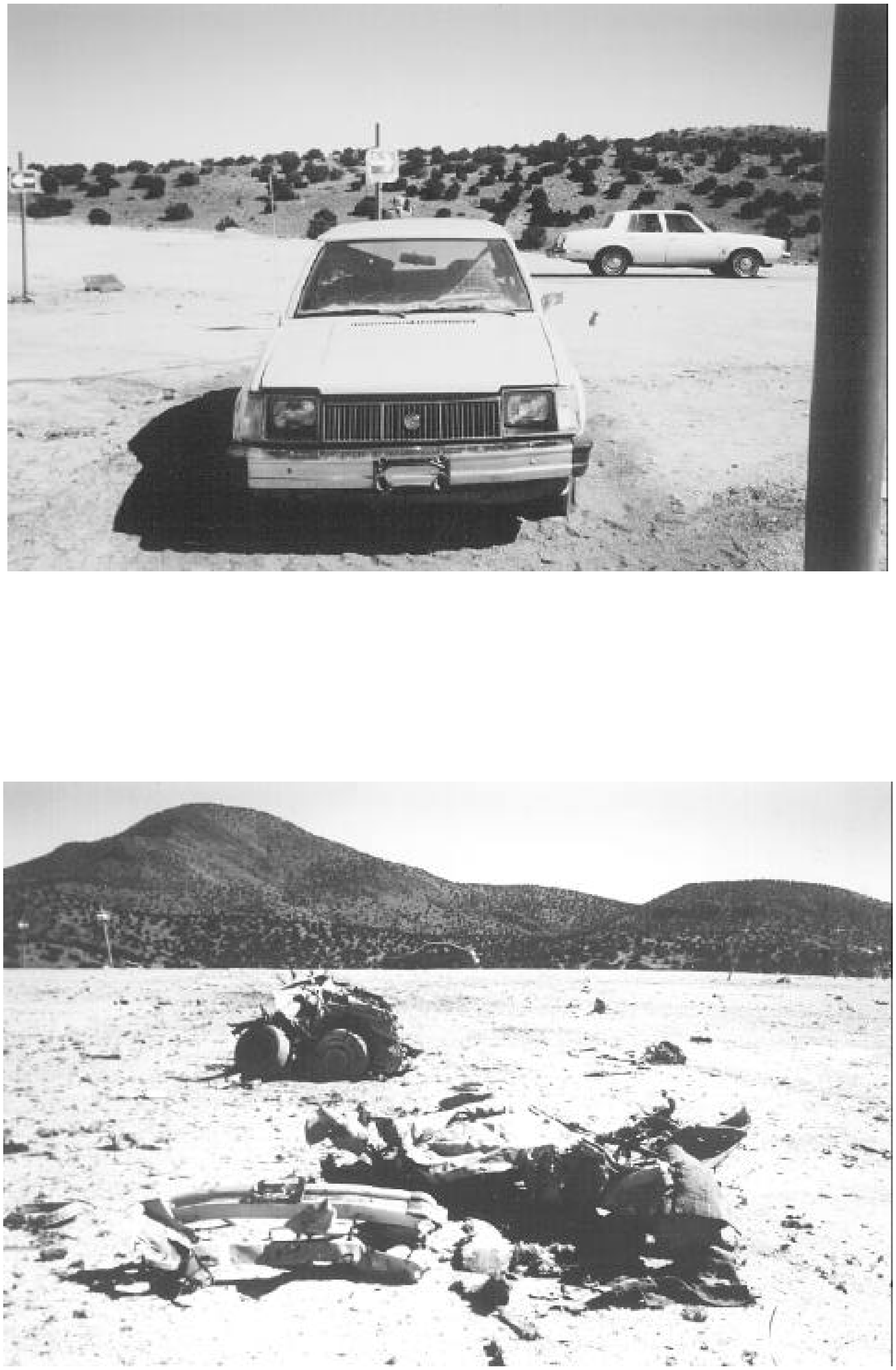

Fig.4 Target effects on a vehicle positioned 4.5m from 454 Kg of Mixture Y

Fig.5 Target effects on a vehicle 4.5m from 454Kg of TNT